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EVALUATION OF THE ION IMPLANTATION PROCESS FOR PRODUCTION OF SOLAR CELLS FROM SILICON SHEET MATERIALS

Quarterly Technical Report No. 1

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spire

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1.0 OBJECTIVES

The objective of this program is the investigation and evaluation of the capabilities of the ion implantation process for the production of photovoltaic cells from a variety of present-day, state-of-the-art, low-cost silicon sheet materials. Task 1 of the program concerns application of ion implantation and furnace annealing to fabrication of cells made from dendritic web silicon. Task 2 comprises the application of ion implantation and pulsed electron beam annealing (PEBA) to cells made from SEMIX, SILSO, heat-exchanger-method (HEM), edge-defined film-fed growth (EFG) and Czochralski (CZ) silicon.

The goals of Task 1 comprise an investigation of implantation and anneal processes applied to dendritic web. A further goal is the evaluation of surface passivation and back surface reflector formation. In this way, processes yielding the very highest efficiency can be evaluated.

Task 2 seeks to evaluate the use of PEBA for various sheet materials. A comparison of PEBA to thermal annealing will be made for a variety of ion implantation processes.

2.0 MATERIALS

During the first quarter, various sheet materials were procured for use in the program. These materials are summarized in Table 1. For some of the materials, there is a large variation in resistivity, as indicated. In addition, the thickness of the wafers is quite variable. The SEMIX material is quite thin and particularly fragile.

3.0 WORK PERFORMED

For the ion implantation in Task 1, tooling was fabricated with which to hold dendritic web samples. This tooling permits the expeditious boron implantation of the back to form the back surface field (BSF). In this quarter, baseline BSF web cells were fabricated using the process shown in Table 2.

TABLE 1.
CHARACTERISTICS OF SHEET MATERIALS PROCURED
FOR USE IN THE PROGRAM

Growth	Source	Resistivity	Surfaces	Comments
1. Dendritic Web				
Lot 1	Westinghouse	2-10 ohm-cm	POL.	Std. Material Dendrites Removed
Lot 2	Westinghouse		POL.	Low Stress
2. SEMIX				
Lot 1	JPL/ASEC	2 ohm-cm	ETCHED	Thin (~150 μm)
3. EFG				
Lot 1	JPL/ASEC	2 ohm-cm	As Grown	
Lot 2	Mobil Solar		As Grown	
4. SiLSO				
Lot 1	Wacker	5-10 ohm-cm	ETCHED	
5. HEM				
Lot 1	JPL/ASEC	6 ohm-cm	ETCHED	
Lot 2	Crystal Systems		ETCHED	
6. Single Crystal				
Lot 1	Wacker	10 ohm-cm	POL	100 CZ
Lot 2	Wacker	1 ohm-cm	POL	111 FZ

Implantation and anneal as shown in Table 2 resulted in front junctions with sheet resistance of 90 ohms-per-square and depth of 0.38 micrometers. The resulting back p^+ implant had a doping concentration above 10^{19} B/cm^3 to a depth of approximately 0.7 microns. Spreading resistance profiles for these implants are shown in Figures 1 and 2.

TABLE 2.
DENDRITIC WEB CELL FABRICATION SEQUENCE

1.	CLEAN	
2.	BACK IMPLANT	
	Ion Species	$^{11}B^+$
	Energy	50 keV
	Dose	5×10^{15} ions/cm2
3.	ANNEAL	
	550°C - 2 hours	
	950°C - 2 hours	
4.	FRONT IMPLANT	
	Ion Species	$^{31}P^+$
	Energy	10 keV
	Dose	2.5×10^{15} ions/cm2
5.	ANNEAL	
	550°C - 2 hours	
	850°C - 15 minutes	
	550°C - 2 hours	
6.	PHOTO PATTERN FRONT	
7.	FRONT AND BACK CONTACT EVAPORATION	
	Ti-Pd-Ag	
8.	METAL LIFTOFF	
9.	SINTER	
10.	PLATE FRONTS	
	10 μm of Ag	
11.	SAW TO 2cm x 2 cm	
12.	TEST	

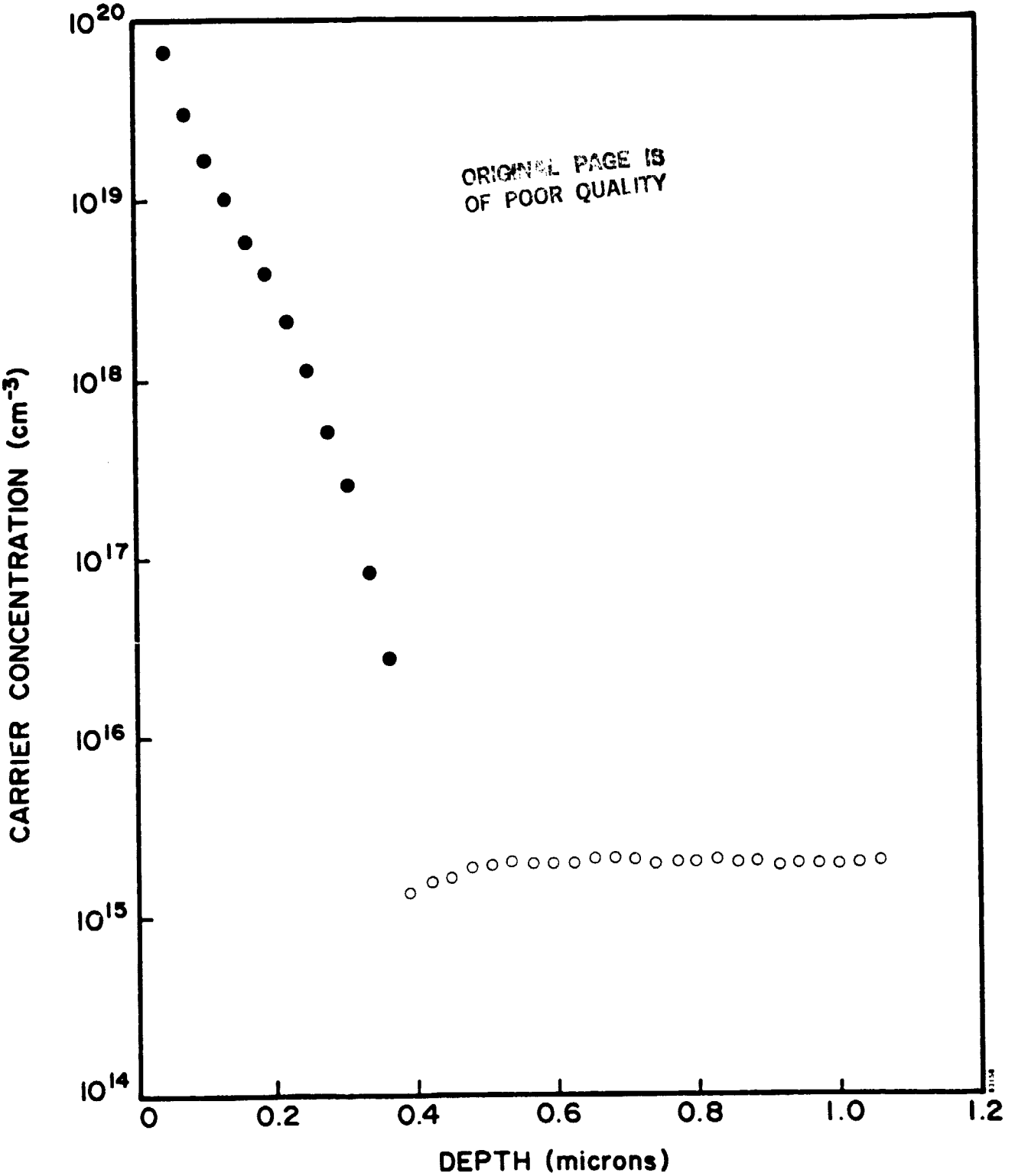

FIGURE 1. SPREADING RESISTANCE ANALYSIS OF THE PHOSPHORUS FRONT JUNCTION.

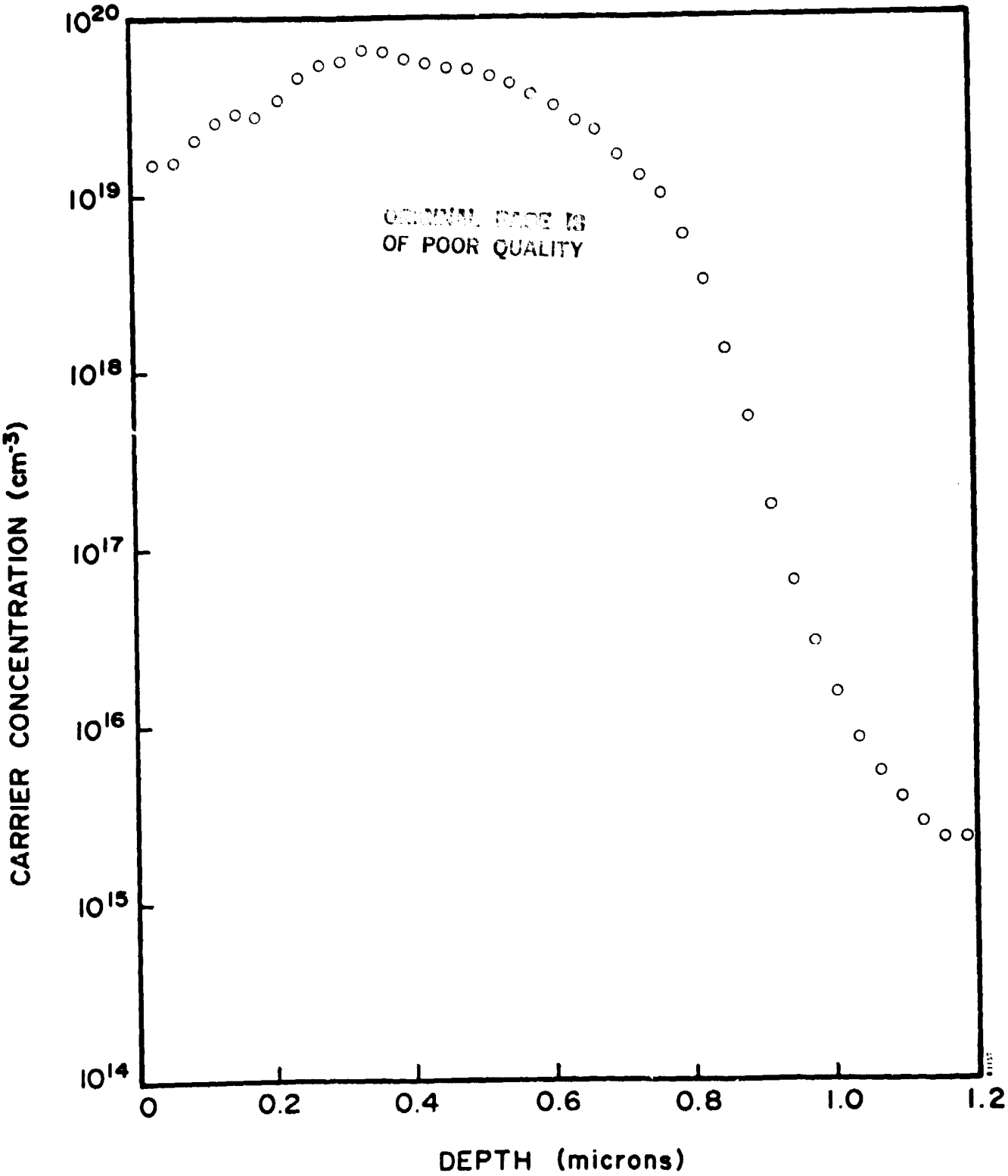

FIGURE 2. SPREADING RESISTANCE ANALYSIS OF THE BORON BSF.

Work in Task 2 concerned establishment of a baseline for sheet material processing. The cell structure was of the n^+-p type and no BSF was employed. The process is summarized in Table 3.

Owing to an equipment problem with the evaporator used for antireflection (AR) coatings, we were unable to coat these cells. Nevertheless, comparison to single crystal controls is entirely meaningful and will be presented in the next section. AR coatings can be applied during the second quarter, if desired.

TABLE 3
SHEET MATERIAL N+P PROCESS SEQUENCE

1. CLEAN
2. IMPLANT FRONT
   - Ion Species: 31P+
   - Ion Energy: 10 keV
   - Dose: 2.5 x 1015 ions/cm2
3. ANNEAL
   - 550°C - 2 hours
   - 850°C - 15 minutes
   - 550°C - 2 hours
4. EVAPORATE BACK METALLIZATION
   - Al-Ti-Pd-Ag
5. SINTER
6. PHOTOPATTERN FRONT
7. EVAPORATE FRONT METALLIZATION
   - Ti-Pd-Ag
8. METAL LIFTOFF
9. SINTER
10. PLATE FRONTS
    - 10 μm of Ag
11. SAW TO 2cm x 2 cm
12. TEST

4.0 SUMMARY OF DATA

All cells were tested under simulated AM1 conditions (100 mW/cm^2). Temperature was maintained at 28°C by a water-cooled test block. None of the cells have AR coatings. For the purposes of comparison, we have assumed that a high quality AR coating would yield a gain in efficiency of 1.45; the corrected efficiency reported in the tables to follow is obtained by multiplying the measured efficiency by this factor.

4.1 Dendritic Web Experiment

Dendritic web and FZ controls were processed as described in Table 2. We observed significant yield problems owing to the fragility of web material without dendrites, and to the inexperience of the staff in handling this material. Final yield was 23% for web samples and 100% for FZ controls.

Table 4 indicates the AM1 performance of the cells. Low J_{sc} for the web cells may be partly attributable to the thickness of the cells (~200 microns); however, the low V_{oc} indicates the possibility of low diffusion length.

TABLE 4.

AVERAGE PERFORMANCE OF BASELINE DENDRITIC WEB BSF SOLAR CELLS

Group	V_{oc} (mV)	J_{sc} (mA/cm2)	FF (%)	Eff (%)	Corrected Eff (%)
Dendritic Web (7 cells)	524 (008)	18.9 (0.7)	75.6 (1.0)	7.48 (0.40)	10.9 (0.6)
FZ Controls (10 cells)	584 (001)	23.2 (0.1)	78.6 (0.5)	10.6 (0.1)	15.4 (0.1)

Notes: Insolation was AM1, 100 mW/cm2. Temperature = 28°C. Cell area = 4 cm2. The corrected efficiency is obtained by multiplying the efficiency obtained from a non-AR-coated cell by 1.45. This is the gain typically realized with a high quality AR coating. Standard deviation shown in parenthesis.

4.2 HEM Baseline Cells

Table 5 shows the average performance of the baseline HEM cells. These cells compare well with the co-processed CZ control group. The higher V_{oc} can probably be attributed to the resistivity difference (HEM:6 ohm-cm, CZ:10 ohm-cm). The lower J_{sc} in the HEM cells is probably the result of diffusion length in the polycrystalline HEM material which is most likely lower than that in CZ. It is interesting that the best cell is superior to the CZ controls. The performance of the CZ controls would be improved by addition of a BSF.

TABLE 5.

AVERAGE PERFORMANCE OF HEM BASELINE CELLS

Group	V_{oc} (mV)	J_{sc} (mA/cm2)	FF (%)	Eff (%)	Corrected Eff (%)
HEM (11 Cells)	553 (010)	20.3 (0.9)	74.0 (2.0)	8.33 (0.53)	12.1 (0.8)
CZ-control (10 Cells)	533 (002)	22.3 (1.8)	73.5 (3.0)	9.07 (0.43)	13.2 (0.6)
Best Hem Cell	567	21.9	74.6	9.25	13.4

Notes: Cell Area = 4 cm2; T = 28oC; Insolation = 100 mW/cm2, AM1. Standard deviation shown in parenthesis.

4.3 SILSO Baseline Cells

Table 6 shows the average performance of SILSO cells. The performance of the best cell is quite comparable to the CZ controls.

TABLE 6.

AVERAGE PERFORMANCE OF SILSO BASELINE CELLS

Group	V_{oc} (mV)	J_{sc} (mA/cm2)	FF (%)	Eff (%)	Corrected Eff (%)
SILSO (15 cells)	523 (005)	20.8 (0.3)	75.0 (1.8)	8.15 (0.25)	11.8 (0.4)
CZ-Controls (10 cells)	533 (002)	22.3 (1.8)	73.5 (3.0)	9.07 (0.43)	13.2 (0.6)
Best SILSO Cell	531	21.2	76.1	8.56	12.4

Notes: Cell Area = 4 cm2, T = 28°C; Insolation = 100 mW/cm2 (AM1). Standard deviation shown in parenthesis.

4.4 EFG Baseline Cells

Table 7 reports the results obtained with EFG ribbon. These results are unsatisfactory, but this is believed to be related to the material itself.

TABLE 7.

AVERAGE PERFORMANCE OF EFG BASELINE CELLS

Group	V_{oc} (mV)	J_{sc} (mA/cm2)	FF (%)	Eff (%)	Corrected Eff (%)
EFG (7 cells)	491 (021)	17.3 (0.7)	62.8 (9.6)	5.38 (1.12)	7.8 (1.6)
CZ-controls (10 cells)	533 (002)	22.3 (1.8)	73.5 (3.0)	9.07 (0.43)	13.2 (0.6)
Best EFG Cell	508	17.6	72.2	6.47	9.4

Notes: Cell Area = 4 cm2; T=28°C, Insolation = 100 mW/cm2 (AM1). Standard deviation shown in parenthesis.

The wafers used were generally characterized by what we take to be SiC particles, sometimes on both sides of the ribbon. This indicates to us that this material is not representative of current EFG technology.

We have recently procured new EFG ribbon (courtesy of K.D. Ravi) and will abandon utilization of the older materials.

4.5 SEMIX Baseline Cells

The SEMIX supplied to us was approximately 150 micrometers in thickness. We were unable to process this material with satisfactory yield. Consequently, the fabrication process could not be completed on any of the wafers.

5.0 ANALYSIS AND CONCLUSIONS

The data presented in the previous section indicates that we have established a baseline for the various sheet materials. The process will need to be repeated for EFG and SEMIX material.

In the next quarter, comparison will be made to pulsed electron beam annealed cells. Since junctions in these cells will be formed by a low temperature process, we will be able to compare the effects of high temperatures on grain boundaries and mechanical strength. Further analysis will be deferred until that time.